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STATE OF CALIFORNIA
The Resources Agency

Department of Water Resources

in cooperation with

Alameda County Water District

BULLETIN No. 147-2

GROUND WATER BASIN PROTECTION PROJECTS: FREMONT SALINITY BARRIER

JUNE 1975

CLAIRE T. DEDRICK
Secretary for Resources
The Resources Agency

EDMUND G. BROWN JR.
Governor
State of California

RONALD B. ROBIE
Director
Department of Water Resources

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FOREWORD

In the Fremont study area in southern Alameda County, ground water extractions exceeded recharge for many years, resulting in extensive salt water intrusion of the ground water aquifers. The extent and nature of the problem and possible solutions have been cooperatively studied by the Department and Alameda County Water District for many years and several reports have been written. Alameda County Water District has reduced the salt water intrusion by augmenting the ground water supplies of the Fremont study area with imported water supplies from the South Bay Aqueduct of the State Water Project and the City of San Francisco's Sunol Aqueduct. Withdrawals from the basin were also reduced by using imported water from the Hetch Hetchy Aqueduct.

The District is now removing isolated volumes of saline water from the ground water system by pumping selected wells. To provide management for the ground water basin, it will also be necessary to prevent movement of additional salt water into the main portion of the ground water basin.

This report recommends a salinity barrier plan including general exploration and location costs, schedules, and design criteria for barrier wells, piezometers, and appurtenant facilities. It also summarizes the results of prior investigations and discusses alternative ways of protecting the ground water supply.

Advanced computer assisted evaluation of the subsurface system has been used to locate the buried stream channels that are the primary avenues of saline water intrusion. Utilization of this technique during the study and during construction increases the reliability of the solution and reduces the cost of the project.

Adoption and implementation of the plan and installation of the barrier are recommended to avoid the severe damage that could occur during a series of dry years.

Ronald B. Robie

Ronald B. Robie, Director
Department of Water Resources
The Resources Agency
State of California

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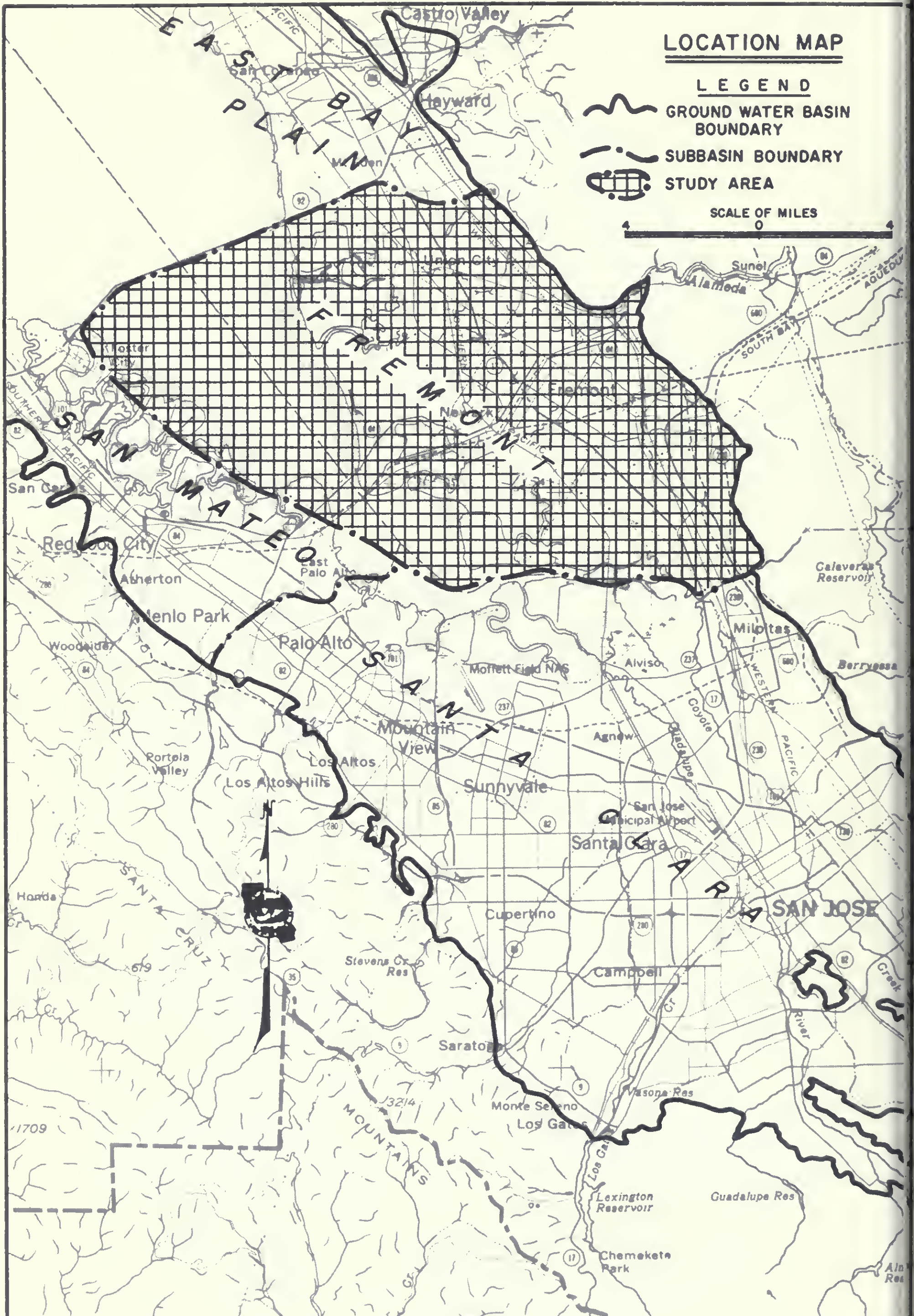
ACKNOWLEDGMENT

The Department of Water Resources and Alameda County Water District wish to thank Alameda County Flood Control and Water Conservation District, Leslie Salt Company, and the Cities of Fremont, Newark, and Union City for permitting installation of test facilities.


LOCATION MAP
LEGEND
GROUND WATER BASIN BOUNDARY
SUBBASIN BOUNDARY
STUDY AREA
SCALE OF MILES
4
0
4
EAST BAY PLAIN
FREMONT
SAN MATEO
SANTA CLARA
SANTA CRUZ
MOUNTAINS
Castro Valley
Hayward
Union City
Sunol
Alameda
Fremont
Newark
Foster City
San Carlos
Redwood City
Atherton
East Palo Alto
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Berryessa
Coyote
Guadalupe
Honda
3214
1709
SOUTH BAY
AQUEDUCT
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PACIFIC
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CHAPTER I. PROBLEM DESCRIPTION AND RECOMMENDED SOLUTION

This report recommends that the solution to the problem of sea water intrusion that exists in the southwestern portion of Alameda County be the construction of a line of wells between San Francisco Bay and the main ground water area. Controlled pumping of the wells would create a depression in the ground water surface and intercept saline waters attempting to intrude the basin. It also discusses the geologic and hydrologic conditions, alternative means of controlling intrusion, and other current projects that affect control of salt water within the ground water area. The study was conducted by the Department of Water Resources in cooperation with Alameda County Water District.

Study Area

The South Bay ground water basin underlies South San Francisco Bay and the lands adjacent to the Bay in Alameda, San Mateo, and Santa Clara Counties. The ground water basin contains three main units: the Fremont study area, containing the Bay and southern Alameda County; the Santa Clara study area to the south; and the San Mateo study area to the west. This report deals with the Fremont ground water area, which contains the Cities of Fremont, Newark, and Union City. The location and boundaries of the study area are shown on Figure 1.

Problem Description

Saline water from San Francisco Bay and adjacent salt ponds has intruded fresh water-bearing aquifers underlying the study area. The saline water intrusion was first noticed in the early 1920's. The intrusion began when ground water levels in the Newark (upper) Aquifer dropped below sea level as ground water extractions began to exceed recharge. The relationship between various aquifers is shown schematically on Figure 2.

At first, the intrusion affected only shallow wells. As the shallow wells were abandoned, deeper wells were drilled; these provided good quality water for about 25 years. Then, beginning in the 1940's, brackish water began to appear in some of the deeper wells. Ultimately, the intrusion extended almost to the base of the hills bordering the east edge of the Bay Plain -- over five miles from the Bay.

The Alameda County Water District first countered the saltwater intrusion by increasing the opportunity for natural flows in Alameda Creek to percolate, and then by (1) augmenting (recharging) the ground water supplies of the Fremont area with imported waters from the South Bay and Sunol Aqueducts, and (2) using imported water from the Hetch Hetchy Aqueduct to reduce ground water withdrawals.

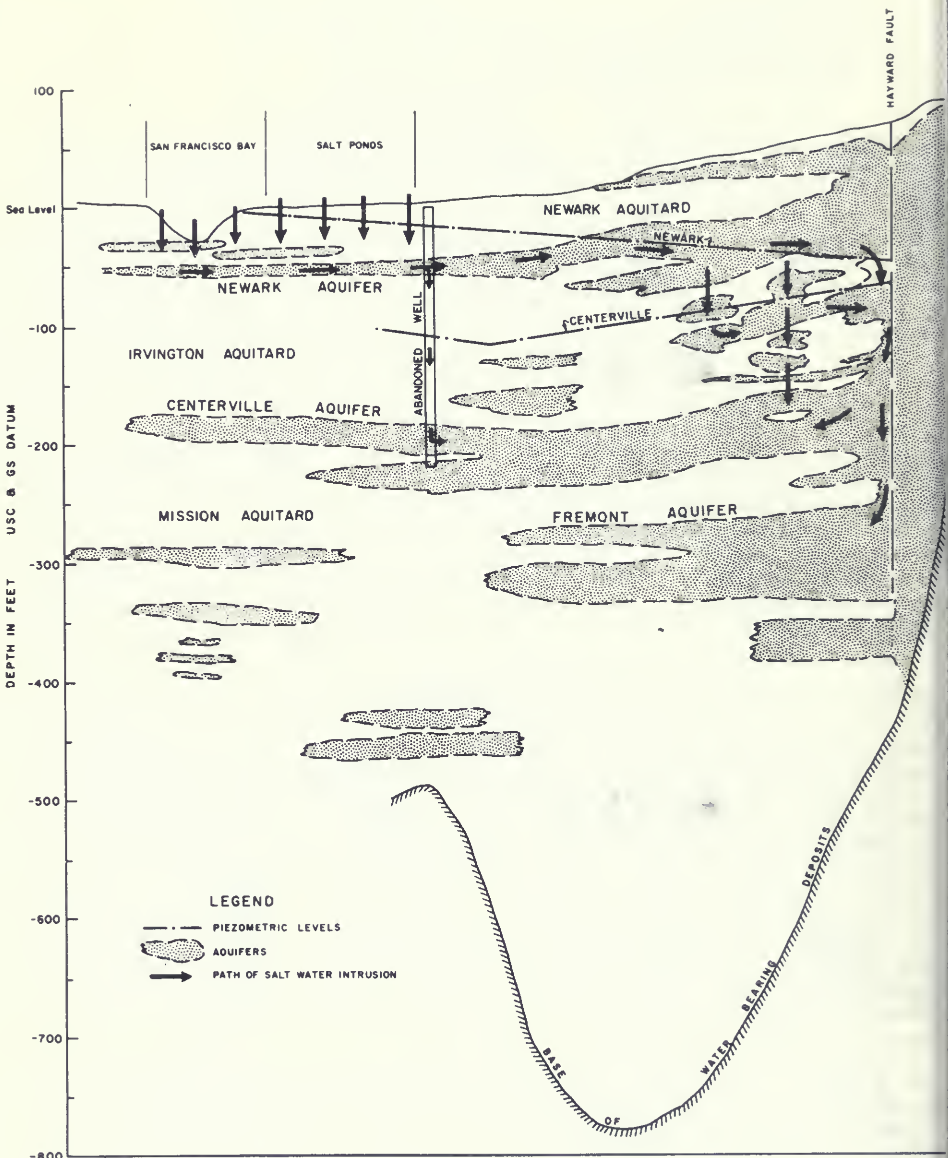


Figure 2 INTRUSION OF SALT WATER INTO THE FREMONT AREA (SCHEMATIC)

Even though water levels have been raised above sea level by these corrective measures, the intruded salty water is still in the aquifers. Moreover, the danger of continuing saline intrusion is still present, particularly during future dry periods.

Physical Setting

The Fremont ground water area is part of the South Bay ground water basin which rims and underlies San Francisco Bay. Physiographically, the South Bay ground water basin is an extensive alluvial and estuarine plain occupying a folded, faulted depression in the earth's crust bordered on the east and west by the roughly parallel ridges of the Coast Range geomorphic province. The folding and uplift of hills and ridges and sinking of the valley largely occurred during late-Pliocene to mid-Pleistocene time, but are still continuing today.

Each stream eroding the uplifted hills dropped its sedimentary load at the edge of the down-dropped basin in a depositional pattern called an alluvial fan. The Niles Cone, in the Fremont ground water area, is one of the largest of the alluvial fans in the San Francisco Bay-Santa Clara Valley trough. The alluvial deposits which form Niles Cone were laid down by Alameda Creek as it meandered back and forth across the almost 12-mile width of the cone.

The sediments dropped by Alameda Creek grade from gravel and boulders at the apex of the Niles Cone to fine sand and silt near the Bay. During periods of normal runoff, stream courses were established with coarse-grained materials being deposited in the channels and fine-grained materials away from the channels. During major floods, the old channels were abandoned and new channels formed down the surface of the fan. At times, the meandering streams would swing back and forth over a relatively short distance, leaving behind braided channel deposits. The abandoned stream channels were buried with younger, usually finer-grained sediments. Those old channels now are encountered as tubular aquifers and convey ground water from the recharge areas toward the Bay. Water level data indicate that some of the aquifers are interconnected in varying degree. In some cases, the buried channels have been cut off by regional tilting and faulting. The locations of subsurface channels are shown in a generalized manner on Figure 3, and in detail in Volume II of Bulletin 118-1, "Evaluation of Ground Water Resources: South Bay, Additional Fremont Area Study".

Sea level did not remain static during the formation of Niles Cone and the other alluvial fans and plains in the Fremont ground water area. Sea level dropped 200 to 300 feet (61 to 91 meters) lower than it is now during the major advances of continental glaciers during the Pleistocene. At such times the ancestral Santa Clara Valley occupied the entire South Bay area. Alameda Creek and other South Bay streams meandered across a verdant valley floor, possibly joining the Sacramento River near the Golden Gate. As sea level rose during interglacial periods, the alluvial channel deposits were buried beneath bay muds. During some interglacial periods, sea level rose higher than it is today. As a consequence, blue marine clays are found interbedded with the alluvial fan deposits of Niles Cone. At times of higher than normal sea level, the sediments deposited by Alameda Creek might be characterized as deltaic, rather than alluvial.

FIGURE 3

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
CENTRAL DISTRICT

GROUND WATER BASIN PROTECTION PROJECTS
SALINITY BARRIER STUDIES, ALAMEDA COUNTY

APPROXIMATE AXES OF AQUIFER DEPOSITION IN ELEVATION INTERVAL +50 FEET TO -70 FEET

SCALE OF FEET
4000 0 4000 8000 12000

LEGEND

◆◆◆ AXIS OF AQUIER DEPOSITIC

═══ PROPOSED BARRIER LOCAT

Recommended Solution

Analysis of the problem and consideration of alternatives has led to the conclusion that the ground water reservoir can be restored and maintained as a usable resource only if three actions are taken at the same time: (1) planned recharge of natural and imported waters; (2) removal from the ground water reservoir of salt water which intruded during prior years; and (3) installation of a barrier to prevent additional salt water from entering the ground water reservoir. Figure 4 is a diagrammatic representation of the recommended solution.

Planned Recharge

Alameda County Water District is effectively utilizing its spreading basins along Alameda Creek to recharge the aquifers in the Fremont ground water area. Water levels have recovered, and water supply and demand are approximately equal on an average annual basis. However, the raised ground water levels are not able to force the already intruded sea water back to the Bay because the combined effect of hydraulic gradient and transmissivity of connections between the Newark Aquifer and the Bay is too small to remove the large volume of saline water in a reasonable period of time.

Removal of Entrapped Salt Water

Work is presently underway on an aquifer reclamation program, the purpose of which is to stop or retard the spread of the salt water already in the basin and to reclaim the intermediate and lower levels of the basin for future use. This program is to develop facilities and to operate them to pump salt water from the ground water basin. The location of aquifer reclamation wells are shown schematically on Figure 5. The salt water will be pumped into flood control and drainage channels, where it will then flow to the Bay. The facilities that will be needed are wells and pumps installed to appropriate depths to intercept this saline water. The cost of the aquifer reclamation program is estimated at $750,000 for the first phase, with an annual operating cost of $250,000 per year.

The aquifer reclamation program requires the use of planned recharge to replace the salt water pumped out with fresh water and also requires a salinity barrier to prevent additional salt water from entering the system.

Fremont Salinity Barrier Project

It is recommended that an underground sea water intrusion barrier be installed between San Francisco Bay and the aquifers under the portion of the study area to be protected. The proposed barrier, which will form an irregular line along the landward edge of the saltwater evaporation ponds west of Fremont and extend about three miles northward and six miles southeastward from the Coyote Hills, is shown on Figure 3 and is described in detail in this report. The estimated cost of the proposed barrier, based on a January 1975 start is slightly above $3 million. The recommended time to complete the barrier is six years.

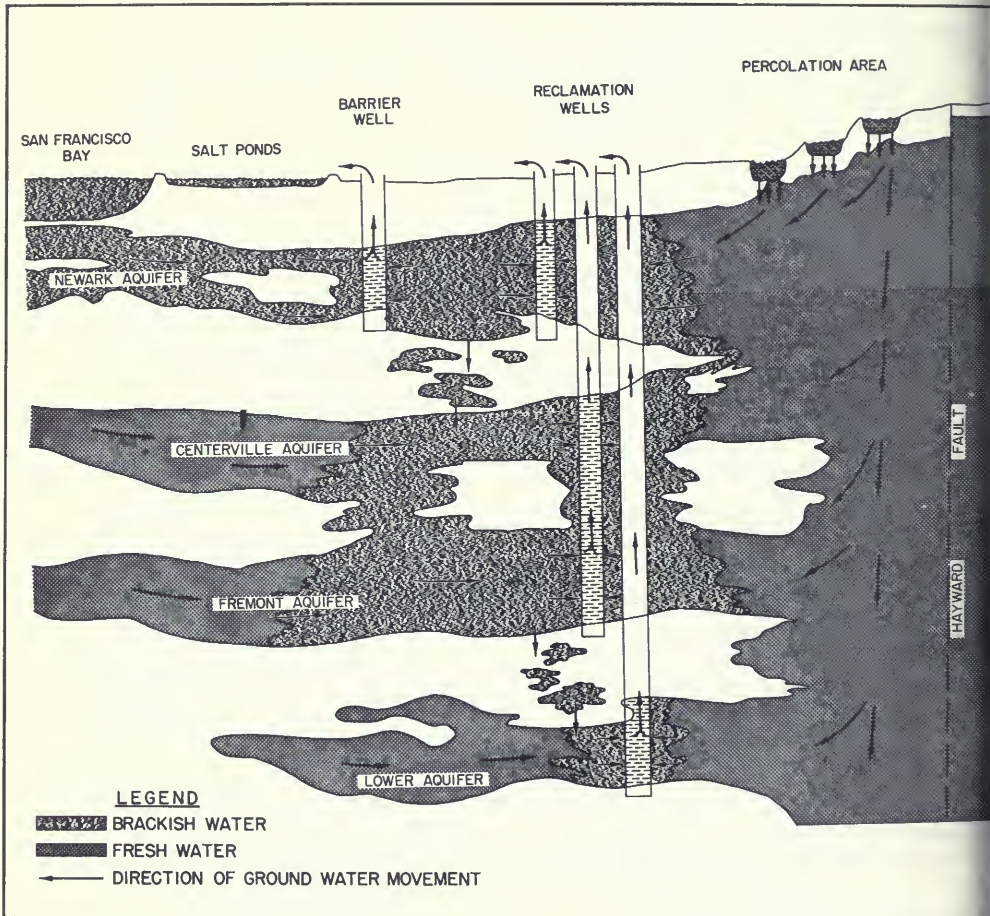


Figure 4. CONTROLLING SALT WATER INTRUSION IN THE FREMONT AREA (SCHEMATIC)

THIS MAP COMPILED FROM U.S.G.S. NILES AND NEWARK QUADRANGLE MAPS, 1968 PHOTO REVISED.

Figure 5. LOCATION OF AQUIFER RECLAMATION WELLS

The feasibility of developing sea water intrusion barriers of various types has been considered, as will be discussed later in this report. There are three compelling reasons for our recommending the pumping type of barrier over the other types: (1) it will not trap saline waters in the Newark aquifer inland of the barrier as would be the case with the other types of barriers; (2) it will not force already intruded saline waters further inland as would be the case with the more conventional recharge mound type of barrier; (3) it alone will provide aquifer reclamation benefits in accelerating the removal of already intruded saline water from the aquifer.

Previous Work

Detailed background information on ground water resources, geology, and sea water intrusion in Alameda County, and on ground water basin protection studies will be found in the following publications:

USGS Water Supply Paper 345, "Ground Water Resources in the Niles Cone and Adjacent Areas, California", by W. O. Clark. 1915.

State Water Commission, "Engineers Report on Investigations on the Niles Cone, 1916-1920", by Paul Bailey and Edward Hyatt, Jr. May 1920.

USGS Water Supply Paper 519, "Ground Water in Santa Clara Valley", by W. O. Clark. 1924.

DWR Bulletin 81, "Intrusion of Salt Water into Ground Water Basins of Southern Alameda County". December 1960.

DWR Bulletin 13, "Alameda County Investigation". March 1963.

DWR Bulletin 74-2, "Water Well Standards: Alameda County". June 1964.

DWR Bulletin 118-1, "Evaluation of Ground Water Resources: South Bay, Appendix A: Geology". August 1967.

DWR Bulletin 118-1, "Evaluation of Ground Water Resources: South Bay, Volume I: Fremont Study Area". May 1968.

DWR Bulletin 118-1, "Evaluation of Ground Water Resources: South Bay, Volume II: Additional Fremont Area Study". August 1973.

DWR Bulletin 63, "Sea Water Intrusion in California". November 1958.

Appendix B: "Report by Los Angeles County Flood Control District on Investigational Work for Prevention and Control of Sea Water Intrusion, West Coast Basin Experimental Project, Los Angeles County". March 1957.

Appendixes C, D, and E (published as one volume), April 1960.

C: Laboratory and Model Studies, Abstract of Literature, and Review of Formulas and Derivations.

D: An Investigation of Some Problems in Preventing Sea Water Intrusion by Creating a Freshwater Barrier.

E: Preliminary Chemical-Quality Study in the Manhattan Beach Area, California.

DWR Bulletin 147-1, "Ground Water Basin Protection Projects: Santa Ana Gap Salinity Barrier, Orange County". December 1966.

DWR Bulletin 147-6, "Ground Water Basin Protection Projects: Oxnard Basin Experimental Extraction-Type Barrier". September 1970.

The following references were used in developing Chapter V, "Environmental Considerations":

Goldman, Harold B., "Hayward Shoreline Environmental Analysis", Hayward Area Shoreline Planning Agency. July 1973.

Jones & Stokes Associates, Inc., "Draft Environmental Impact Report on the Alameda County Water District Aquifer Reclamation Program". March 1973.

CHAPTER II. GEOHYDROLOGY

The geology and hydrology of the Fremont ground water area are discussed in varying detail in the publications on Alameda County and Santa Clara Valley listed above. The most detailed discussion of geologic conditions which affect the occurrence and movement of ground water in the Fremont area are presented in DWR Bulletin 118-1, "Evaluation of Ground Water Resources: South Bay, Appendix A: Geology" (1967); "Volume I, Fremont Study Area" (1968); and "Volume II, Additional Fremont Area Study" (1973). Recent (1971-72) mapping of the surface formations in the alluviated areas of Alameda County is available from the U. S. Geological Survey as Miscellaneous Field Studies Map MF-429, "Geologic Map of Late Cenozoic Deposits, Alameda County, California".

Geologic Units and Their Water-Bearing Properties

The geologic formations of the Fremont ground water area have been divided into two main groups: nonwater-bearing and water-bearing. The nonwater-bearing are practically devoid of water; however, in certain areas they may provide limited quantities of ground water to domestic or stock wells. In contrast, the water-bearing formations are capable of yielding ground water to wells in sufficient quantities for all types of uses.

Nonwater-Bearing Formations

The nonwater-bearing rocks are exposed in the highland area to the east of the valley and in the Coyote Hills. These rock types also occur below the valley floor at depths down to 1,500 feet (457 meters). Nearly all of these rock types are consolidated and of low permeability; they do not have primary openings large enough to allow movement of ground water. In these rock types ground water exists largely in secondary openings formed by fractures, joints, shear zones, and faults. These secondary openings provide minimal storage space and avenues for movement of ground water; thus, these rocks provide only small quantities of water to wells. Because secondary openings are not present uniformly in any given rock type or geographic area, their ability to yield ground water to wells is quite variable and is dependent on local structural conditions.

The quality of ground water in the nonwater-bearing rocks is often poor. Most of these rocks are of marine origin; consequently, finer-grained zones still retain some of the original sea water. Some of the coarser-grained rocks have been flushed and contain fair to good quality ground water.

Water-Bearing Formations

The sediments making up the water-bearing formations are unconsolidated to semiconsolidated. In contrast to the older nonwater-bearing rocks, the water-bearing formations contain ground water in primary openings between the grains. These grains range in size from clay to silt, sand, and gravel, and reach a maximum of boulder size in certain areas.

The water-bearing formations fall into two groups: the Santa Clara Formation of Plio-Pleistocene age; and Quaternary alluvium of Pleistocene to Recent age.

Santa Clara Formation. The Santa Clara Formation is exposed in the Mission Upland east of the Hayward fault. The Santa Clara Formation underlies the Quaternary alluvium and rests unconformably on older formations of the nonwater-bearing group. It consists of semiconsolidated alluvial and lacustrine deposits including obscurely bedded, poorly sorted, pebbly sandstone, siltstone, and clay, plus lenses of sand and gravel. Exposures show the effects of chaotic bedding and curved slickensided surfaces due to multiple and continued sliding.

In the Mission Upland, exposures of the Santa Clara Formation in several sand and gravel quarries show well-sorted gravel lenses with practically no fines. These beds occur up to several feet thick and many feet long and appear to be very permeable. If they are common throughout the Mission Upland, they may account for the relatively high production of some wells in this area. Stream crossbedding, scour and fill, and an extreme range in sorting all point to stream deposition in this area. This formation has been folded and faulted since deposition.

Well data show that the permeability of the Santa Clara Formation tends to decrease from east to west toward the bay; hence, the highest production of wells is reported to be in the Mission Upland. Well logs show that the sediments also tend to decrease in grain size and permeability with depth.

Quaternary Alluvium. Quaternary alluvium is the most important water-bearing formation in the Fremont ground water area. Permeability of the alluvium is generally high; consequently, all the water wells with large production draw their supply from it. The alluvium is composed of generally unconsolidated gravel, sand, silt, and clay. The sand and gravel deposits have the highest permeability and are thus the major aquifers; conversely, silt and clay layers have low permeability and, therefore, form aquitards.

Alluvium along the eastern margin of the area was deposited by streams which drained the highlands and debouched onto a series of alluvial fans. Only the most recent of these fans are expressed physiographically today. The coarser sediments characterize the apexes of the fans. The alluvial sediments near the edge of San Francisco Bay are predominantly finer-grained, with only occasional thin stringers or buried channels of fine sand and gravel. These extend beneath the Bay, where they are interbedded with thick layers of marine and estuarine clays. The following aquifers have been defined in the alluvium: Newark, Centerville, Fremont, and Lower. They are described in the section on Ground Water Hydrology. Their relationship is shown schematically on Figure 2.

The depth to the base of Quaternary alluvium could not be determined because of the marked similarity in lithology between it and the underlying Santa Clara Formation.

Ground Water Hydrology

The Fremont ground water area has been divided into four ground water subareas, each having some degree of independence. These are the Niles Cone, Dry Creek Cone, Warm Springs Plain, and Mission Upland ground water areas. The largest of these, the Niles Cone, is the subarea most affected by sea water intrusion and the one of concern in this report.

The eastern part of the Niles Cone, namely the apex of the Alameda Creek alluvial fan, is extremely permeable and yields large quantities of ground water to wells. The stratified nature of the alluvium permits rapid transport of ground water from the recharge area at the eastern edge of the subarea west of the Hayward fault, to points of withdrawal to the west.

The Niles subarea is composed of a series of flat-lying aquifers separated by extensive clay aquitards. In the vicinity of Niles, the alluvium is composed almost entirely of gravel. To the west, interbedded clay beds are thicker. The nature of the various aquifers and aquitards in the Niles subarea has made it possible to delineate specific aquifers and to correlate them from one well to the next.

Nonsteady (fluctuating) flow of ground water to wells has traditionally been analyzed by considering each aquifer as an independent geologic and hydrologic unit. In the Fremont area at least three such aquifers exist, namely, the Newark, Centerville, and Fremont aquifers. Each of these aquifers is confined from above and below by layers that manifest significantly less permeability. These layers, or confining beds, previously identified as aquicludes, have been found to possess definite permeability characteristics, to be compressible to some degree, and to release some water from storage. We call these confining beds "aquitards". Aquifers above or below the aquitards are termed "leaky aquifers".

Aquifer and Aquitard Characteristics

The three uppermost aquifers in order downward are the Newark, Centerville, and Fremont aquifers. Deeper, and unnamed, aquifers are referred to as the Lower Aquifer.

Newark Aquitard. Nearly all of the Niles subarea is covered by a thick veneer of silt and clay called the Newark aquitard. It is present east of the Hayward Fault in an area usually pictured as being completely devoid of a clay cover. In general, the thickness of the Newark aquitard increases from the eastern edge of the Niles subarea westward toward San Francisco Bay. Because the aquitard has relatively low permeability, it retards widespread infiltration of surface water into the underlying Newark aquifer. The thicker the aquitard, the more effective it is in preventing salt water from moving into the underlying aquifer from San Francisco Bay and the salt evaporation ponds. Conversely, thinner portions of the aquitard are less effective in preventing salt water intrusion.

Newark Aquifer. The Newark aquifer, lying directly below the Newark aquitard, is an extensive gravel layer located between 60 and 140 feet (18 and 43 meters) below the ground surface. The aquifer is found east of Coyote Hills and underlies almost the entire Niles subarea. Nearly all logs of wells in the Niles subarea indicate the presence of the Newark aquifer. Wells at Ravenswood, on the western side of the Bay, show that the aquifer continues underneath the Bay both north and south of Dumbarton Bridge. The Newark aquifer is the conductor of salt water eastward from under San Francisco Bay. This eastward migration of salt water indicates that the Newark aquifer is fairly continuous throughout the Niles subarea.

The thickness of the Newark aquifer ranges from over 140 feet (43 meters) at the Hayward fault, to less than 20 feet (6 meters) at the western edge of the subarea. Those portions of the subarea in which the materials are particularly thick represent zones where coarse materials have been continuously deposited by streams. The zones extend to the Bay around the north and south ends of Coyote Hills.

Of major importance to the understanding of salt water intrusion and its control are the locations of the subsurface channels connecting the Newark aquifer with lands underlying the salt evaporation ponds and South San Francisco Bay. The locations of the subsurface channels connecting the various aquifers with the main recharge areas are important in planning recharge programs and in selecting well locations for the extraction barrier. The approximate location of the subsurface channels is shown on Figure 3.

Not only must the subsurface channels be more precisely located, but their width, thickness, grain size, transmissivity, and other characteristics need to be determined for optimum location and design of the individual barrier wells. Transmissivity is one of the formation constants of an aquifer which indicates the rate at which water is transmitted through a unit width of the aquifer under a unit hydraulic gradient. Knowledge of transmissivity is indispensable in planning the well production from the aquifer channels to intercept all of the intruding sea water.

Irvington Aquitard. An extensive thick clay aquitard, the Irvington aquitard separates the Newark aquifer from the Centerville aquifer and largely protects this lower aquifer from receiving saline water from the Newark aquifer. The aquitard is thickest under San Francisco Bay and thins to the east as the aquifers become thicker. Well log data suggest that the aquitard has several thin zones which may allow some downward movement of saline water from the Newark aquifer into the Centerville aquifer.

Centerville Aquifer. Another important aquifer is the Centerville aquifer, which covers nearly as much of the Niles subarea as the overlying Newark aquifer. It is found nearly everywhere, except immediately to the west of Coyote Hills. The Centerville aquifer lies at an average depth of between 180 and 200 feet (55 and 61 meters) below ground surface.

The Centerville aquifer extends under San Francisco Bay as a flat-lying gravelly sand layer. The aquifer is the main source of ground water for wells located on the marsh along the western side of the Bay, and for wells near Dumbarton Strait.

Mission Aquitard. As interpreted from well logs, the Mission aquitard is a uniformly thick clay layer which extends from the Hayward fault westward to and beneath San Francisco Bay.

Fremont Aquifer. The Fremont aquifer is separated from the overlying Centerville aquifer by the Mission aquitard. The Fremont aquifer is not as well defined as the Newark and Centerville aquifers, but is generally thicker and more productive. From well log data it can be inferred that the Fremont aquifer exists primarily in that portion of the Niles subarea east of Coyote Hills. The depth to the Fremont aquifer varies from 300 to 390 feet (92 to 119 meters) below ground surface. Near the Hayward fault the Fremont aquifer merges with the overlying aquifers.

Lower Aquifer. Wells in the Niles subarea, reaching depths greater than 400 feet (122 meters), intercept highly productive deeper aquifers. Where wells are close together, these deeper aquifers can be correlated for short distances. The correlatable portions suggest that the aquifers are relatively flat-lying. The aquifers below 400 feet (122 meters) may extend beyond the limits of the Niles subarea and serve as zones for migration of ground water. The configuration of water levels in wells tapping the deeper aquifers shows a gradient toward the northwestern boundary of the Niles subarea. This suggests that ground water in the Niles subarea moves toward the north to meet water moving outward from the adjacent San Leandro Cone. The deeper aquifers appear to be recharged by infiltration of water from both Alameda and San Lorenzo Creeks.

The extensive nature of the deeper aquifers is important because if the Niles subarea becomes degraded by salt water to considerable depths, the outward movement of ground water may also degrade the quality of water in adjacent areas. Some communities north of the Niles subarea use ground water from these deeper aquifers; thus, any sea water intruded into the Niles subarea could migrate toward pumping depressions and degrade ground water in these deeper aquifers.

Sea Water Intrusion. Before wells were drilled in the Fremont ground water area, fresh ground water filled the aquifers extending beneath San Francisco Bay and reportedly appeared as freshwater springs in the bay floor and around the base of Coyote Hills. The forebay for recharge to all aquifers is the apex of the Alameda Creek alluvial fan west of the Hayward Fault. Sea water intrusion began when production of ground water through wells exceeded recharge and the ground water levels dropped below sea level.

Intrusion of saline water into the Newark aquifer, shown diagrammatically on Figure 2, is influenced by a number of conditions. The Newark aquifer does not appear to be in direct contact with the saline water of San Francisco

Bay, with the following possible exceptions: (1) in the Dumbarton Narrows, where tidal currents may have scoured the bay mud and exposed the aquifer; (2) in other areas where dredging may have breached the clay cap; or (3) where abandoned, unsealed wells allow salt water inflow.

Tests conducted during 1971-72 under the guidance of Professor Paul A. Witherspoon of the University of California at Berkeley, have suggested two possible sources of degradation of the Newark aquifer: (1) salt water migration by chemico-osmotic diffusion, and (2) migration through the unbroken aquitard induced by the downward hydraulic gradient from the salt ponds and bay. Although the downward flow of salt water per square foot of aquitard may be relatively small, the computed amounts over the total area of bay and salt ponds is significantly large.

Pumping from the ground water basin induced landward movement of intruded saline waters through the Newark aquifer to the common forebay and thence down into the lower aquifers. Since the static water level in the Newark aquifer is higher than the level in the Centerville aquifer, some saline water has moved and may still move through unsealed, defective wells and through natural interconnections. After the saline water reaches the lower aquifers, it moves bayward down the hydraulic gradient toward the pumping trough. Figure 2 shows diagrammatically the movements of the intruding saline waters.

The Alameda County Water District conducts an extensive monitoring program to determine the location and movement of the salt water within the basin. Over 400 wells are sampled for salinity twice each year. This provides part of the basic information needed for protecting the usable parts of the basin and for proposed rehabilitation work.

CHAPTER III. GENERAL METHODS OF CONTROL OF SEA WATER INTRUSION

Intrusion of sea water into aquifers and design and construction of barriers to repel the intrusion are governed by physical laws which are relatively simple in theory but difficult to apply because of inherent complexities of ground water basins.

There are several mechanisms by which sea water intrusion can occur in a ground water basin adjacent to an ocean or bay. These mechanisms all relate to the lowering of ground water level elevations and the development of a landward hydraulic gradient which allows the heavier sea water to move inland. Under natural conditions in a coastal ground water basin there is a balance between inflow, outflow, and change in storage. Part of the outflow is freshwater leakage to the ocean, resulting in a stabilized saltwater-freshwater interface. As the ground water resource is developed by increased pumping, water levels lower to accommodate the new supply and demand conditions and the saltwater-freshwater interface moves inland. Saline water may enter and degrade freshwater aquifers in the following ways:

1. Direct intrusion from the ocean into coastal aquifers as a sea water wedge.

2. Direct downward movement of saline and brackish tidal or inland bay waters through natural or man-made breaks in underlying clay layers.

3. Downward movement of degraded shallow aquifer waters through the natural breaks in and over the landward ends of aquitards (clay layers) into deeper aquifers.

4. Slow downward movement of saline waters through clay layers into underlying aquifers.

5. Spilling or cascading of saline waters into underlying aquifers through improperly constructed or abandoned wells.

As illustrated by Figure 2, at least the last three of the foregoing, and possibly the second, are involved in the saline water intrusion into the Newark aquifer and thence into the lower aquifers in the Fremont area.

Sea water intrusion may be prevented or controlled by applying one or more of the following general methods:

1. Raising ground water levels to sea level or above by reductions in extractions or by rearrangement of the areal pattern of pumping draft, or both.

2. Direct recharge of overdrawn aquifers to maintain ground water levels at or above sea level.

3. Maintenance of a freshwater ridge or injection barrier along the coast.

4. Development of a pumping trough between the saline water sources and the main ground water pumping areas.

5. Combination injection-extraction barrier.

6. Construction of static physical subsurface barriers.

7. Entrapped air barrier.

Implicit in all methods of control is the need for management of the ground waters of the basin by some agency. Assurance of an adequate water supply to support the economy of lands now dependent upon the local basin water supplies, without impairment, must be a primary consideration in any program for control of sea water intrusion. This may involve importation of supplemental water from nontributary sources, or additional conservation of local supplies, or both. Maintaining or, if possible, increasing conservation of locally available water resources generally would be a major factor in the formulation and application of a program for control of sea water intrusion.

The basic objectives of any salinity control program are applicable in the Fremont ground water area. These are: (1) to prevent further encroachment, and (2) to reduce the area already affected by sea water intrusion. Comprehensive engineering, geologic, hydrologic, and water quality investigations have been conducted to obtain the information necessary for a proper determination of the method or methods of control to be used.

A more detailed description of the seven general methods of controlling sea water intrusion and their use or potential applicability in the Fremont area follows.

Reduction of Ground Water Extractions and Controlling Pumping Patterns

Control consists of reducing ground water extractions to allow water levels to be restored to elevations at or just above sea level and of maintaining those elevations except for short periods of peak demand.

The restoration and maintenance of water levels to such elevations within a basin suffering a large cumulative water supply deficiency would require the importation of large amounts of supplemental water for direct use, and the reservation of all the natural supply for basin replenishment. This method does not, by its very nature, permit full utilization of the ground water basin storage capacity.

A correlative method consists of rearranging the pumping pattern. If the area of major extractions were moved inland from the coastal portion of the basin, the pumping trough would also move inland. If the trough were below sea level, intrusion would continue. However, the oceanward side of the pumping trough would assume a flatter landward gradient, slowing the movement of ocean water. At the same time, the landward side of the pumping trough would assume a steeper seaward gradient, increasing in many cases the subsurface inflow of fresh water from inland areas. These modified gradients would serve to retard somewhat the further incursion of sea water but would increase the area abandoned to intrusion. The Alameda County Water District used this method to retard saline intrusion as the municipal use of ground water replaced use for irrigation of agriculture. The District constructed most of its new wells in the eastern portion of the basin, with the majority of them east of the Hayward Fault.

The problem of sea water intrusion in the Fremont ground water area is too far advanced to be solved simply by reducing extractions or changing pumping patterns. The record indicates at least 50 years of intrusion, which has left a large volume of saline water in the basin. The intrusion would have advanced more rapidly had there been a more highly permeable connection between the Bay and the Newark aquifer. This once-favorable aspect is now a disadvantage because the intruded sea water cannot be rapidly flushed back to the Bay as ground water levels are raised above sea level. The flushing that takes place will probably be at a relatively slow rate.

Artificial Recharge

The introduction of large volumes of local or imported water into the depleted basin by spreading in the basin forebay can raise ground water levels to elevations above sea level. An additional source of water must be available for this purpose and the physical conditions must be present so that recharge can be increased. In areas of confining clay layers, injection wells could be used. The gradient from the recharge area steepens to carry the additional flow. Again the landward gradient between the pumping wells and the sea changes to a seaward gradient. Pumping continues at the previous level. If sufficient information is available, the recharge and pumping can be controlled to minimize the waste of fresh water to the ocean. An advantage of this system is that increasing recharge by spreading is relatively inexpensive. A possible limitation to this method is that the aquifer may not have adequate capacity to carry the required additional flow.

Alameda County Water District is effectively utilizing its spreading basins along Alameda Creek to recharge the aquifers in the Fremont ground water area. This is vital to the continued use of the ground water basin. However, the raised ground water levels are not able to force the already intruded sea water back to the Bay because the transmissivity of the connections between the Newark aquifer and the Bay is too limited to remove the large volume of saline water in a reasonable period of time.

Another major disadvantage of the artificial recharge method in the Fremont area is that the usable ground water storage capacity of the basin is decreased by maintaining high ground water levels. This reduces the safe yield capacity of the basin by reducing the volume of water that can be stored in wet years for use in dry years.

Maintenance of a Freshwater Injection Ridge

The formation of an injection ridge, pressure barrier, or ground water mound along the coastal segment of a ground water basin by the use of injection wells or by surface spreading, or a combination of both methods, would depend on whether free ground water or pressure conditions exist, as determined by detailed engineering and geologic investigation. In basins where free ground water conditions exist along the site of the proposed ridge, a mound of more or less uniform height could probably be maintained by continuous application of water in spreading grounds. In basins where pressure conditions exist and injection wells are utilized, the ridge would consist of a series of peaks in the piezometric surface with saddles between. In either case, the required elevation of the ridges and saddles above sea level would be determined by: (1) the distance of the base of the aquifer below sea level; (2) its transmissibility; (3) the height of freshwater head necessary to displace sea water to the base of the fresh water-bearing deposits; and (4) the existing hydraulic gradient in the aquifer. Here again, rearrangement of the pattern of pumping draft might be beneficial. Extractions from the basin would have to be brought into balance with the total usable recharge to the basin, including the flow landward through the aquifer from the ridge.

An injection ridge would be just as effective in repelling sea water intrusion as would a seaward hydraulic gradient extending the entire distance from the forebay to the ocean. An advantage is that water levels inland from the injection ridge could be lowered below sea level to permit the use of a greater amount of underground storage capacity; at the same time, water that would otherwise be wasted after the basin fills could be salvaged. Most of the water used to maintain the injection ridge would flow landward into the basin and consequently could be recovered. The small portion of the injected water that would move toward the ocean under the influence of seaward hydraulic gradient in the average coastal basin would be lost.

Operation of an injection barrier presents certain problems. Perhaps the most serious difficulty is that, because of the very nature of the method, it requires the maintenance of piezometric heads above sea level along the injection alignment; these heads may also exceed ground surface elevations. This condition could cause waterlogging in the vicinity of the injection wells. Experience has also shown that frequent well rehabilitation is necessary to maintain required injection rates at minimum heads.

Operation of an injection barrier in the Fremont area may be feasible, but only after the intruded saline waters have been flushed from the Newark aquifer. An injection barrier is not feasible now, because the already intruded saline waters inland from the wells would be trapped in the aquifer and would be forced to move farther inland toward the producing wells.

Pumping Trough or Extraction Barrier

Development of an extraction barrier would require maintaining a pumping trough adjacent to the Bay when the Newark aquifer is below sea level. The pumping trough is formed by a line of pumping wells located between the water supply wells and the sea water source. The barrier wells must be pumped at rates which will intercept all the sea water moving landward toward the supply wells. This method can provide the added benefit of removing saline water from an aquifer where encroachment of sea water is far advanced.

After equilibrium is reached, the ground water levels in the trough must be lower than any other point in the aquifer. For this system to eventually reach equilibrium, pumping must be reduced or freshwater recharge increased by at least an amount slightly larger than the rate at which sea water is intruding. This, of course, means that either water demand must be lessened or an alternative supply must be made available. In the Fremont area the water supply and ground water recharge have been increased.

The important items in this method are monitoring of the ground water levels at the pumping trough and determining the amount of water which must be pumped at the barrier wells. The barrier pumping requirements will vary widely with the actual conditions, but may equal or substantially exceed the amount of water which historically intruded, depending on the water demand and supply relationship. The closer to the Bay the control wells are located, the greater will be the pumping requirement.

In the Fremont ground water area, the pumping trough or extraction barrier has the advantage of removing intruded saline waters from the Newark aquifer as an extension of the aquifer reclamation program while preventing further sea water intrusion. These are essential characteristics of the proposed Fremont Salinity Barrier.

Combination Injection-Extraction Barrier

An additional dynamic barrier is a combination injection ridge and pumping trough for both unconfined and confined ground water basins. The pumping trough would be operated nearest the ocean, with the injection ridge located farther inland. A combination barrier would require about one-third as much extraction to achieve the same effect as a pumping trough alone, and would require slightly smaller quantities of injected fresh water to achieve the effect of an injection ridge alone.

This combination may merit some consideration in the Fremont area after the intruded saline waters have been extracted from the aquifers.

Static Physical Subsurface Barriers

A static barrier method would involve the construction of a subsurface barrier similar to a positive cutoff structure in permeable materials beneath a dam. The purpose of this subsurface barrier would be to reduce the permeability of the water-bearing materials and thereby preclude subsurface inflow of sea water. (Subsurface outflow of fresh water would also be precluded.) On the landward side of the barrier, pressure levels could be drawn down below sea level by an amount limited only by the effectiveness of the barrier.

Various methods of construction of a subsurface barrier, such as sheet piling, puddled clay cutoff wall, mixed-in-place soil and cement, or some other form of physical structure may be feasible. Injection of emulsified asphalt, cement grout, bentonite, silica gel, calcium acrylate, plastics, and other materials to form a vertical zone of reduced permeability may also be used to create an adequate barrier. A barrier constructed from these materials would probably be permanent and would demand little or no maintenance.

A dual-purpose installation could be provided by a physical barrier combined with a sanitary landfill if the depth to the base of the water-bearing materials were not too great, and if adequate leachate control were provided.

A static barrier could be established by freezing the water-bearing materials. However, high cost of both installation and operation would preclude consideration of this method in the Fremont area.

A major problem in evaluation of static barriers in the Fremont ground water area is that many unknown factors are involved. Barriers of this type and magnitude have never been constructed; experience has been limited to cutoff walls up to 60 feet (18 meters) below dams and up to 45 feet (14 meters) deep beneath levees along the Columbia River and at San Pedro in Los Angeles County, respectively. None of these has extended to the depth (120 feet + (30 meters +)) required for a sea water intrusion barrier near the Coyote Hills. Unknown quantities include feasibility of construction, ability of the barrier to withstand a high differential head, and the possible effects of tectonic disturbances on the barrier. In addition to these unanswered questions, construction of a static barrier would neither remove already intruded saline waters nor alleviate a possible subsidence that could result if this basin were partially dewatered.

Ground Water Control by Entrapped Air

This dynamic method has never been tried as a sea water intrusion barrier except in pressurized caissons. The method may be applicable under some geologic conditions, so an introduction to the idea appears justified.

Air entering an aquifer during the development of a well can cause the well to become "air locked". This is the result of capillary forces at the air-water interface in the tiny intergranular spaces of the aquifer which are sufficient to resist movement of ground water toward the well even against high hydrostatic heads. If an entire aquifer could be caused to become air locked by the introduction of air into the water-bearing materials, this method could provide an economical alternative for preventing movement of ground water or saline water in an aquifer. Once a thick air barrier is established, air injection would be required only intermittently for maintenance.

The air barrier concept is relatively new, and will require extensive field development and testing under various geologic and hydrologic conditions to prove that it could provide a low-cost barrier to ground water movement in a complexly channeled aquifer such as Newark aquifer without secondary problems such as venting of the air through the ground surface as a "blow out".

CHAPTER IV. RECOMMENDED FREMONT SALINITY BARRIER PLAN

The salinity barrier selected for the Fremont area must not only protect the ground water system against further intrusion, but also must provide a means of removing the brines which had previously intruded the system. Of the several methods of controlling sea water intrusion discussed in Chapter III, the pumping barrier is the method that best meets both requirements. Previous work by the Department in both the Oxnard and Fremont areas assures that a pumping barrier is physically feasible.

The pumping barrier will consist of a series of wells which will be pumped to create a trough in the subsurface water surface. Water levels in the various buried stream channel deposits comprising the Newark aquifer will be lowered to a level where all the salt water intruding from the Bay and salt evaporation ponds would be captured and returned to the Bay in the nearest flood control channels.

A slope will be established on the ground water surface between the pumping trough at the wells and the recharge area at the percolation ponds to induce the intruded brines in the Newark aquifer to move toward the wells for discharge to the Bay.

Pumping Barrier Plan Concept

The Coyote Hills form a natural impermeable barrier in the Newark aquifer in the center of the proposed salinity intrusion barrier. The plan is to develop a barrier extending from the north and south ends of the Coyote Hills to the northern and southern ends of the Newark aquifer.

General Barrier Design

The design concept for the salinity barrier is to utilize the natural barrier of the Coyote Hills as the central portion of the barrier. The north and south portions, or extensions, of the barrier will tend to fall along the arc of a circle having its center somewhat north of the apex of Niles Cone, the alluvial fan deposited by Alameda Creek. The distortion of the arc to the north is due to the predominant streamflows and alluvial deposition being oriented in that direction.

The barrier would be composed of wells in the Newark aquifer which would be pumped to intercept the salt water along the barrier line. The barrier wells would be located inland of the salt evaporation ponds but as far to the west as possible. This is to create as much active storage within the protected part of the basin as possible and prevent additional leakage of salt brines into the Newark aquifer during operation of the barrier wells. The resulting alignment is shown conceptually on Figure 6. The depth of the barrier will be the depth of the Newark aquifer, which varies from sea level to -130 feet.

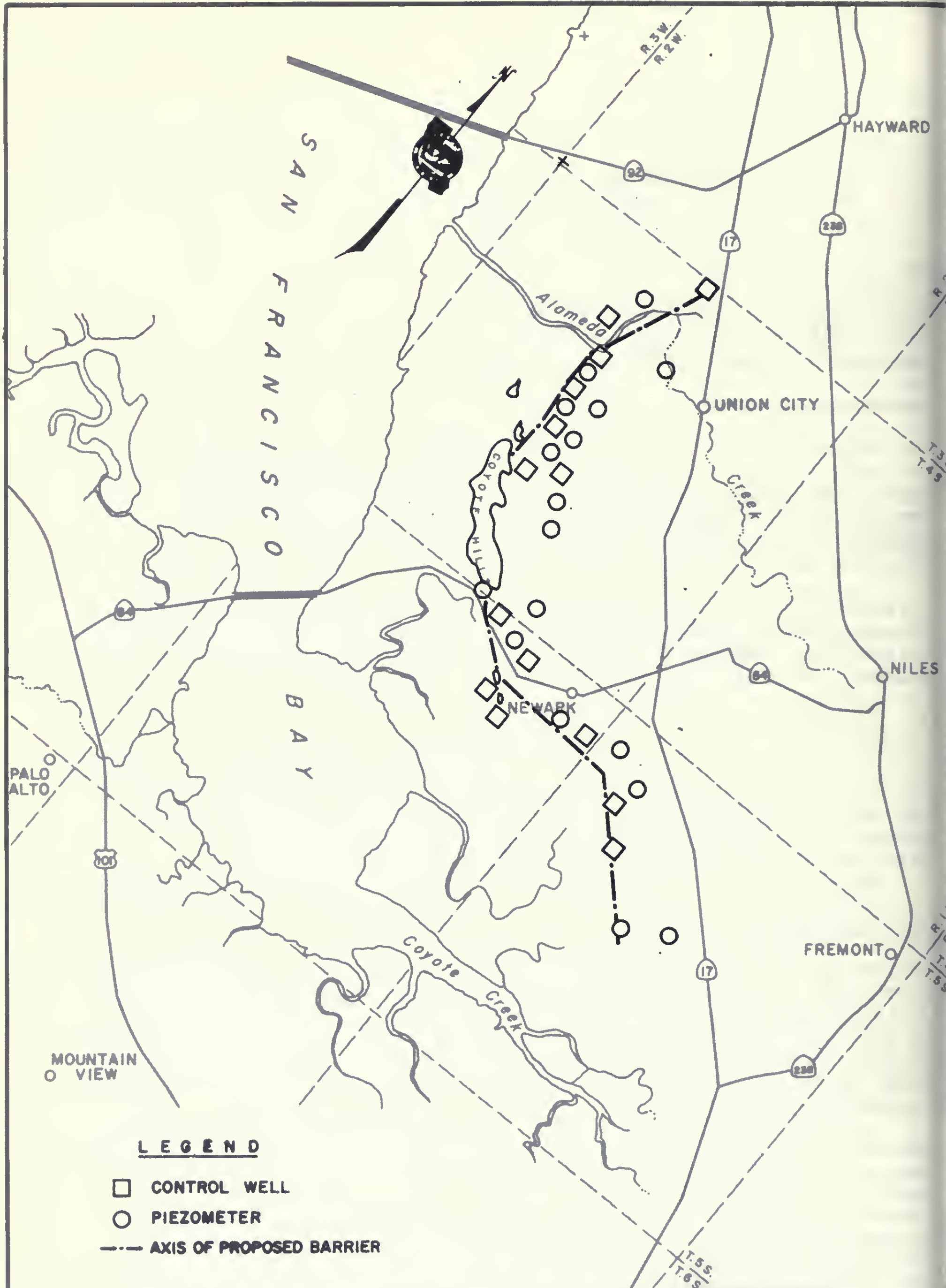


Figure 6. CONCEPTUAL PLAN FOR PROPOSED BARRIER

A critical problem in designing the barrier is selecting the optimum locations for the barrier and piezometer wells. If the Newark aquifer were uniformly permeable, the wells could be evenly spaced. But it is neither uniformly permeable nor uniformly distributed. Rather, the aquifer is made up of a zone of buried, irregular stream channel deposits. These also provide the main channels for salt water intrusion.

The design concept is to accurately locate the subsurface stream gravel deposits by use of the GEOLOG digital computer program developed by the Department. This program facilitates geologic analyses of subsurface data and the identification of primary depositional patterns. Wells will be drilled into each of the primary subterranean channels to intercept the salt water before it enters the central part of the ground water basin. This approach should be less costly and more efficient than the conventional approach of spacing barrier wells at 1,000 to 2,000-foot intervals.

Piezometers will be located around the wells to monitor water levels and quality, indicate the effectiveness of the wells, and be part of a control system for the wells. The locations of the centers of subsurface channel deposition, based on current information, are shown on Figure 3. Additional test holes will be required as part of the program since the barrier alignment is beyond the area of good subsurface information.

Barrier Operation

The barrier wells would be pumped to form a trough in the ground water levels of the Newark aquifer. This would intercept the salt water as it moves inland from the bayward side of the barrier. Thus, it would protect the Newark aquifer inland of the barrier from further salt water intrusion.

Initially the barrier will probably be operated with the water levels in the Newark aquifer above sea level. This will be done to evacuate the intruded salt water that is already east of the barrier line. In essence, this would be an extension of the Alameda County Water District's aquifer reclamation program which is presently in progress.

The ultimate purpose of the barrier would be to create additional active storage in the protected part of the basin and thus increase the basin's fresh water yield. To accomplish this, the Newark aquifer would be drawn down below sea level in dry years, and the barrier would be used to protect it from salt water intrusion. During wet years, or when additional supplemental supplies from the State Water Project and from Del Valle Reservoir are available, the Newark aquifer would be refilled. Thus, the barrier would allow more water to be pumped safely from the basin during dry years than is presently possible.

Barrier Development

The final design of the barrier will require more information than has been developed in the planning and feasibility studies. In addition, studies of construction materials that are presently underway must be completed. One current study comprises an evaluation of the corrosion characteristics of various types of metals and materials that could be used for the barrier. The information would be used for selecting materials for construction of wells and pumps that would be the least adversely affected by the highly saline environment where the barrier wells will be located.

The proposed salt water intrusion barrier requires equipment reliability to be extraordinarily high because operation of the barrier is expected to extend far into the future. Providing equipment with adequate life expectancy poses unusual problems. For example, waters rich in chlorides are particularly corrosive to most of the common construction materials. Also, solids tend to precipitate from highly saline water and cause rapid blockage of water entrance ports in well casings.

Current Work -- Construction Materials Research Program

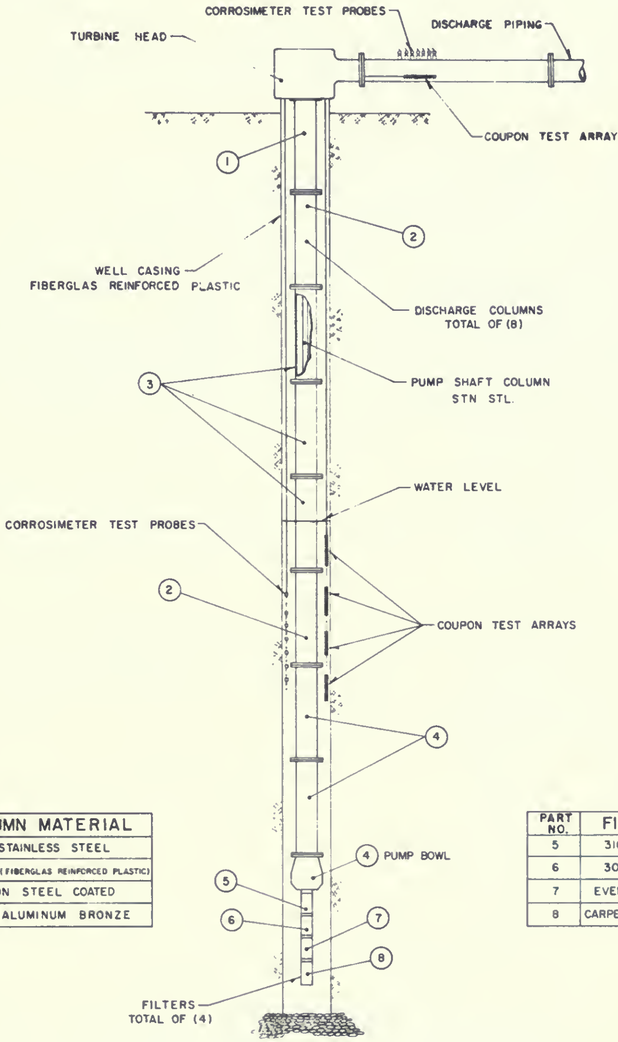
The current research project was needed as an aid in developing specifications for materials for well construction and for barrier pumping equipment. The two-year project provides for evaluation of corrosion resistance of materials in three different ways and under both static and dynamic conditions.

Two wells were selected for the research, each with water quality reflecting the typical conditions expected in the barrier wells. One well is pumped, the other is not.

Research methods for determining the relative corrosion resistance and plugging tendencies of various materials were selected from the recommended practices of the National Association of Corrosion Engineers (NACE), procedures of the American Society for Testing Materials (ASTM), and methods developed by the staff of the Alameda County Water District. The three selected methods are (1) weight change of metal coupons in arrays of specimens, (2) change in electrical resistance of corrosimeter test probes, and (3) on-line operation of a pump specially fabricated to include different test materials. The general arrangement of the test materials and arrays in a test well is depicted on Figure 7.

Metal Coupons. This test, conducted in both static and dynamic modes, positions small metal samples in arrays, each specimen being electrically isolated from all other specimens. Arrays are redundant to the extent required for the 24 months of the project. At 6-month intervals an array is removed from the well, disassembled, cleaned ultrasonically, examined and weighed precisely. Metal weight change is calculated and mathematically converted to corrosion rate in inches per year. Pitting rate is also calculated. Direct comparison of metals under test in identical environments is then possible.

Electrical Resistance. If metal specimens of known cross section and length are included in a modified Wheatstone bridge circuit, electrical resistance can be precisely determined. With certain circuit modifications, the balancing potentiometers in the bridge can be read directly in thousandths of an inch, and the instrument and probe thus become a unit for determining instantaneous and long-term corrosion rates on the test specimen. As the cross section of the metal is reduced due to corrosion, the electrical



PART NO.	COLUMN MATERIAL
1	316 - STAINLESS STEEL
2	F.R.P. (FIBERGLAS REINFORCED PLASTIC)
3	CARBON STEEL COATED
4	NICKEL ALUMINUM BRONZE

PART NO.	FILTER MATERIAL
5	316 - STAINLESS STEEL E.L.C.
6	304 - STAINLESS STEEL
7	EVERDUR SILICON BRONZE
8	CARPENTER STN STL - 20 C.B.S

Figure 7. TYPICAL TEST PROBES & TEST ARRAYS INSTALLATION

characteristics change and can be read on the instrument as corrosion rate. Electrodes of various metals are positioned in the nonpumped well, the pumped well, and in the discharge line of the test pump. These are labeled "Corrosimeter Test Probes" on Figure 7. Electrical readings are made and can be compared directly with all other readings taken from other specimens. Calculations convert the resistance reading into pitting rates for direct comparison.

Research Test Pump. Certain materials were selected for test pump fabrication. The test unit was designed to determine performance of metals, nonmetals, coatings, fabrication techniques, inlet velocity effects on filament wound screens, both corrosion and plugging tendencies, and installation problems resulting from nonstandard designs. The test pump components were carefully "measured" and inspected prior to installation. Comparison of the measurements of the various components at the end of 24 months with the installed values will show performance characteristics of the materials. The test pump has a further important role in that the discharge of the pump is used as the dynamic test medium for both coupon and electrical test probes. Corrosion rates of metals in moving corrosive water may be significantly different from the rates in quiescent water.

In selecting metals for testing in the corrosive ground water environment, those commonly used in relatively noncorrosive environments were selected first as a basis for comparison. Certain metals were excluded from the test on the basis of past experience with unsatisfactory performances in similar environments.

The following criteria were considered in the final selections of materials:

1. Performance as reported in various published technical articles.

2. Past experience in similar environments.

3. Availability.

4. Machinability.

5. Cost.

6. Physical and Mechanical Properties.

Metals and nonmetals selected for the program are shown in Table 1.

Grey cast iron and austenitic ductile iron were not included in the evaluation program. Past experience has shown that grey cast iron in chloride rich water results in extreme graphitization or selective corrosion. Austenitic ductile iron has been found to be susceptible to pitting under long-term quiescent conditions.

Some of the plastics were considered, but their mechanical properties for uses other than well casing are not adequate.

Table 1

METALS AND NONMETALS USED IN EVALUATION PROGRAM

Corrosion Coupons and Electrical Probes

Metal	Designation
Austenitic Chromium - Nickel Stainless Steel	American Iron and Steel Institute, Type 304
Austenitic Chromium - Nickel Stainless Steel	American Iron and Steel Institute, Type 316
Austenitic Chromium - Nickel Stainless Steel	American Iron and Steel Institute, Type 316 ELC
Silicon Bronze	American Society for Testing Materials, B99
Aluminum Bronze	American Society for Testing Materials, B169-D
Hot Rolled Carbon Steel (Copper Bearing Steel)	American Society for Testing Materials, A-303
Carbon Steel	American Iron and Steel Institute, C-1010
Carpenter Alloy Stainless Steel	Carpenter 20Cb3
Red Brass	American Society for Testing Materials, B145
Aluminum	Alloy #6061-T6

Nonmetalic Material

Fiber Reinforced Plastic (Fiberglas)

Coating

Thermal-curing Epoxy, Dry Powder Form (3M-#203)

The specially designed research pump was assembled using fiber-reinforced plastic pipe, coated carbon steel pipe, several bronzes, coated cast iron, and one type of stainless steel. The assembly was designed to maintain electrical isolation of different types of metals except for shafting, pump bowls, and impellers. The pump is equipped with specially designed screen-section assemblies specified to produce inlet velocities about ten times greater than would the inlet velocity design for casing perforations. Inspection of these various components at the end of the two-year operation, final evaluation of all test data, comparison of performance, and cost evaluations will provide data which will be needed for the final design and specifications for the pumping equipment, well screens and other elements in the barrier design program.

Proposed Barrier Development Work

The proposed work is broken down into two phases. The first phase will develop all of the additional information required for the final design of the barrier. The second phase will be the final design and construction of the barrier. The general sequence of activities comprising the phases is outlined in Figure 8.

Phase I. Geology and Exploratory Work

This phase will produce all of the detailed information necessary to determine the final locations and to establish the size of each of the barrier wells. In addition, many of the piezometers will be constructed during this phase.

The proposed work tentatively consists of drilling 8-inch steel-cased wells approximately 120 feet (37 meters) deep and about 1,000 feet (305 meters) apart along the alignment of the barrier. The information from these new well logs will be programmed into the computer by the Department of Water Resources to give information required for improving the depositional analysis to locate the axes of the channels of coarse sand and gravel and thereby to determine the optimum locations for the barrier wells. Where possible, the exploratory wells will be saved for use as piezometers.

Some of these steel-cased exploratory wells will be developed and pumped for aquifer pump tests. These tests will provide information on the transmissivity of the aquifer between the pumped well and nearby piezometers and on the drawdown characteristics of the aquifer. The results of the analyses of the data will be used to determine the final location of each of the barrier wells, their required pumping capacity, and to adapt the design of each well to meet the geologic conditions in each location.

The pump tests will be run with a gasoline-engine-powered pump and could be continued for as long as two or three weeks at any specified location to determine the hydraulic characteristics of the aquifer.

Routine, time-consuming activities which must precede the exploratory work include: obtaining permits from various public agencies and property owners; right-of-way acquisition in some areas; and location of underground

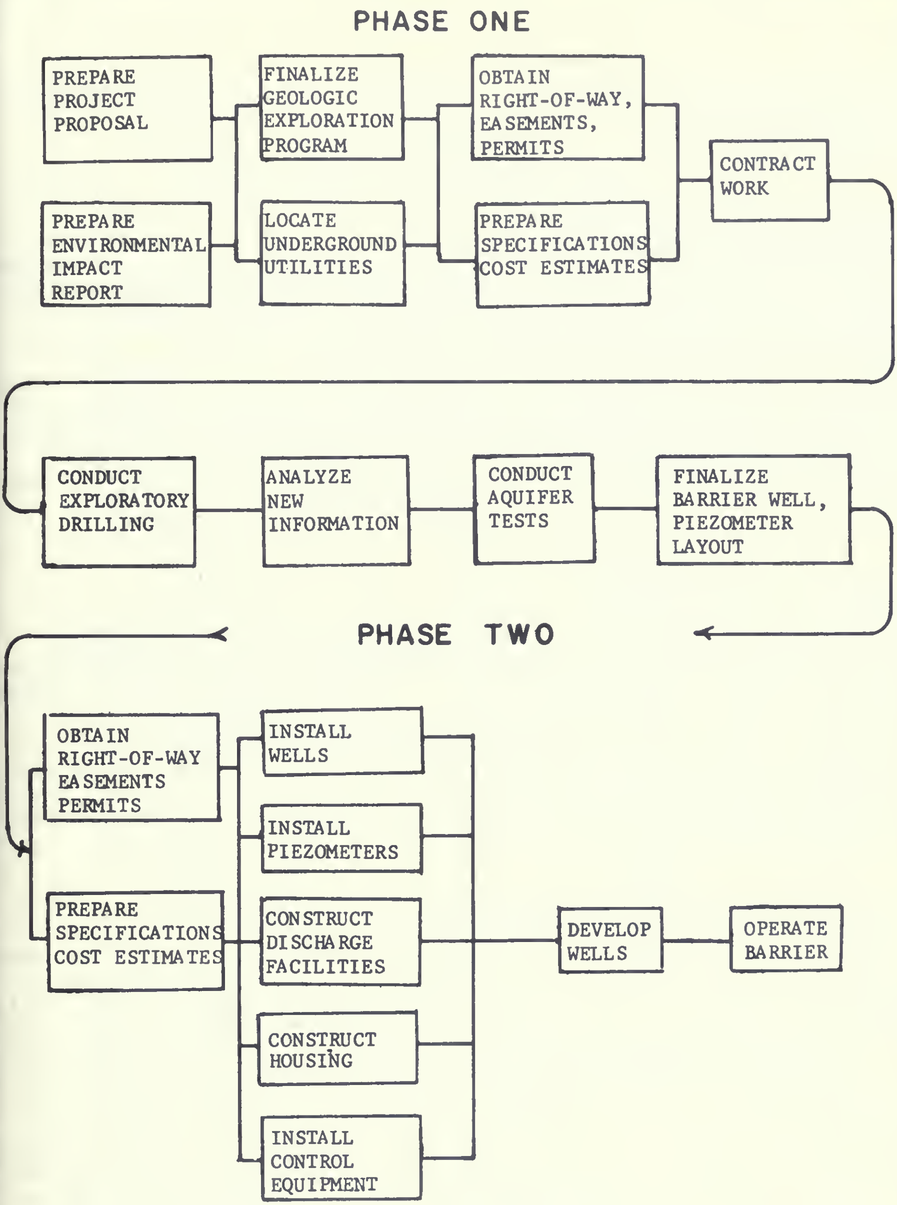


Figure 8. FLOW CHART OF DEVELOPMENT WORK

utilities which need to be avoided. The Phase I work will require about three years for completion. A detailed cost estimate of Phase I is given in Table 2.

Phase II. Design and Construction

The information from Phase I will be used to design the final barrier wells. Phase II will begin when sufficient Phase I information is developed along portions of the barrier to allow for the final design and construction and when funds are available.

During Phase II any rights-of-way or easements that were not acquired during Phase I and that are necessary would be acquired. In addition, permits will be obtained from the San Francisco Bay Regional Water Quality Control Board and from Alameda County Flood Control and Water Conservation District for discharge of waters from the barrier wells into flood control and/or navigable channels.

Permanent Piezometers

The permanent piezometers will probably be either 4- or 6-inch diameter, plastic-cased wells, which are either slotted or screened at appropriate locations in the aquifer. These would be drilled to the bottom of the Newark aquifer, probably by the rotary method. The final diameter of the piezometer wells will depend on (1) the monitoring equipment to be used, and (2) a convenient size for future maintenance of the piezometers. The tops of the piezometer wells will probably be housed in concrete vaults with steel lids. In city streets, the lids will be at road surface. The District has similar piezometer installations in service at the present time. A typical installation is shown in Figure 9.

Barrier Well Design and Construction

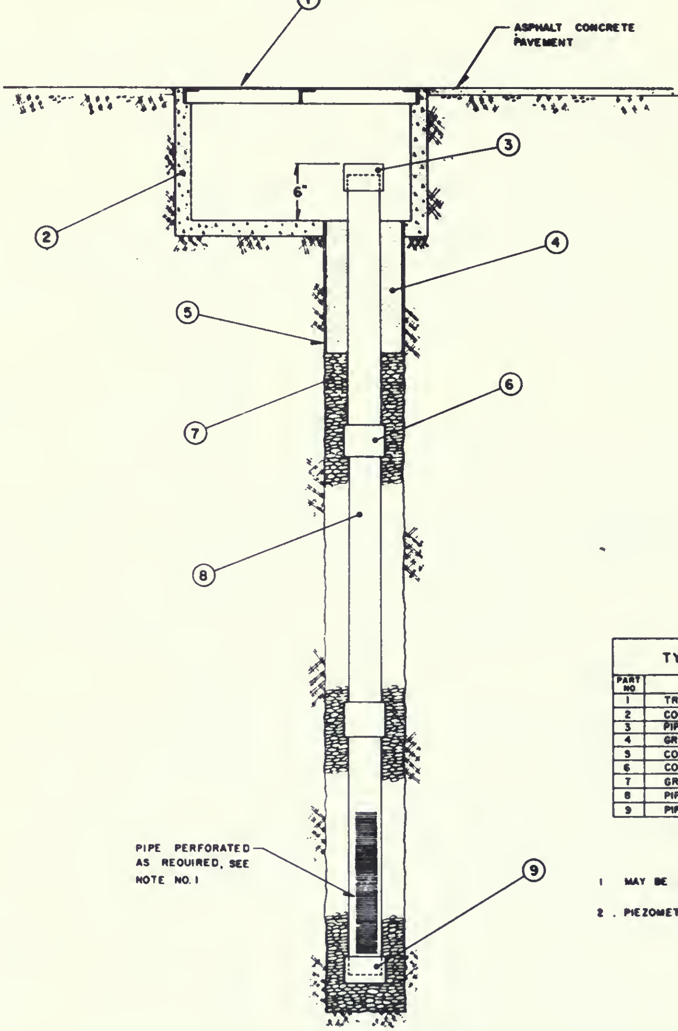
Design of the barrier wells will be based on the pump test information derived from Phase I. The wells will probably vary from 10 inches to 16 inches in diameter, depending on the required pumping rate from each well. They will be gravel-packed wells constructed to the bottom of the Newark aquifer, which is approximately 120 feet deep. They may be constructed either by the rotary or the reverse circulation rotary method, depending on geologic conditions and depth to water. The rotary method generally requires the use of drilling mud which has a tendency to plug aquifers in the immediate vicinity of the well. The reverse circulation rotary method uses water which avoids plugging aquifers, but runs the risk of collapse of the uncased hole if circulation is stopped. Therefore, use of the reverse circulation rotary method requires around-the-clock operation, with completion of the work in about 72 hours.

The casing will be either plastic or stainless steel. This will depend upon the results of the materials research that is currently underway, costs, and other factors which would be evaluated during final design. The perforated sections would be well screens of either plastic or stainless steel. This choice depends on the results of the materials research investigation, costs,

Table 2

COST ESTIMATE
PHASE I -- GEOLOGY AND EXPLORATORY WORK
(Estimate Based on March 1974 Costs)

Item	Activity		Cost
1	Engineering location of 100 exploratory holes		$ 3,300
2	Engineering investigation of underground facilities		1,900
3	Engineering preparation of contract for exploratory holes		1,700
4	Phase I land acquisition - Acquisition of fee title or easements for 30 exploratory holes		
	Engineering	$ 44,600	
	Acquisition	145,400	190,000
5	Construction of 100 exploratory holes		
	Engineering	$ 81,500	
	Construction - 100 steel-cased 8-inch wells @ $2,472	247,200	328,700
6	Development of 25 exploratory holes		
	Engineering	$ 9,200	
	Swabbing, baling, pump installation and removal, and development pumping	11,000	20,200
7	DWR computer geological analysis		10,000
8	Preliminary design of barrier well discharge lines based on final well locations		1,300
Total Cost of Phase I (March 1974 estimate)			$557,100
Total Cost of Phase I assuming January 1975 start, 3 years for completion, and 10% per year cost escalation			$741,100



PART NO	DESCRIPTION
1	TRAFFIC COVER
2	CONCRETE VAULT BOX
3	PIPE CAP (6" SCHEDULE 40 PVC)
4	GROUT SEAL
5	CONTROL CASING
6	COUPLING (6" SCHEDULE 40 PVC)
7	GRAVEL PACK
8	PIPE (6" SCHEDULE 40 PVC)
9	PIPE PLUG (6" SCHEDULE 40 PVC)

TYPICAL PARTS LIST

- NOTES -

1 MAY BE PERFORATED PIPE OR WELL SCRE

2 . PIEZOMETER WELL SIZE 4" TO 10" DIAMETER

Figure 9. TYPICAL PIEZOMETER WELL

availability, and evaluation of long-term maintenance problems. A typical design for a barrier well is shown in Figure 10.

Pump Design. Line-shaft pumps with electric motors would be used for the barrier wells. The approximate flow rates and drawdown will have been determined during Phase I. Final flow rate and drawdown will be determined after pump testing each barrier well after construction. The materials to be used for the pumps, columns, and associated equipment will be determined from the current materials investigation. The cost estimates for the barrier pumps and motors were based on a capacity of 500 gallons per minute from an 8-inch diameter pump with a 20 horsepower electric motor.

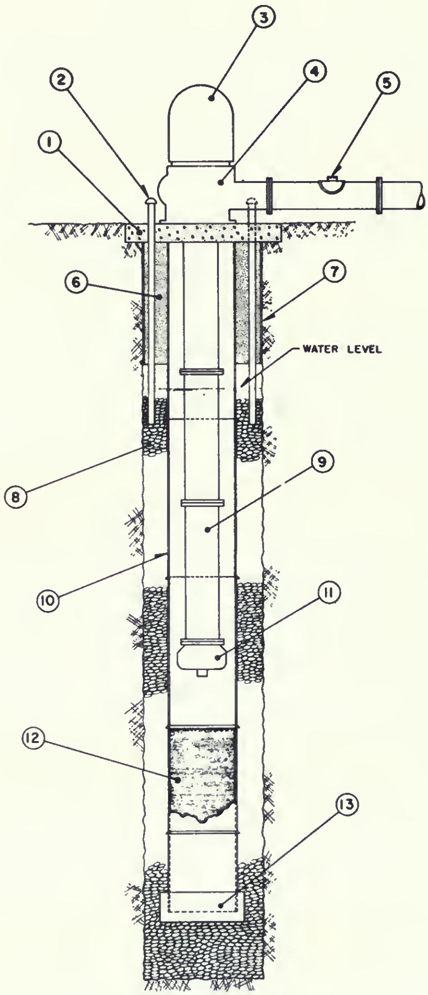
Electric Power Service. The electric power service would be obtained from Pacific Gas & Electric Company. It would be 460 volts. The power lines would be underground in accordance with city ordinances.

Pump House Design. Each pump house will be constructed of wood for esthetic reasons. Each would have a concrete slab floor approximately 8 by 12 feet. The peak of the roof would be approximately 9 feet from ground surface. The roof and one wall would be removable for entry of service equipment for future pump maintenance and repair. The pump houses will be insulated for soundproofing, if this is found to be necessary. A typical pump and housing design is shown in Figure 11.

Discharge Facilities. The discharge line will consist of a steel pipe from the pump to a location underground and just outside of the pump house, and an underground plastic pipe to carry the water from there to the nearest flood control channel. The diameter of the pipe will depend on the volume of flow and the distance to the flood control channel. This information will not be available until it is developed during Phase I. Energy dissipating structures and other appurtenant facilities in the flood control channels will be constructed as required by the Alameda County Flood Control and Water Conservation District.

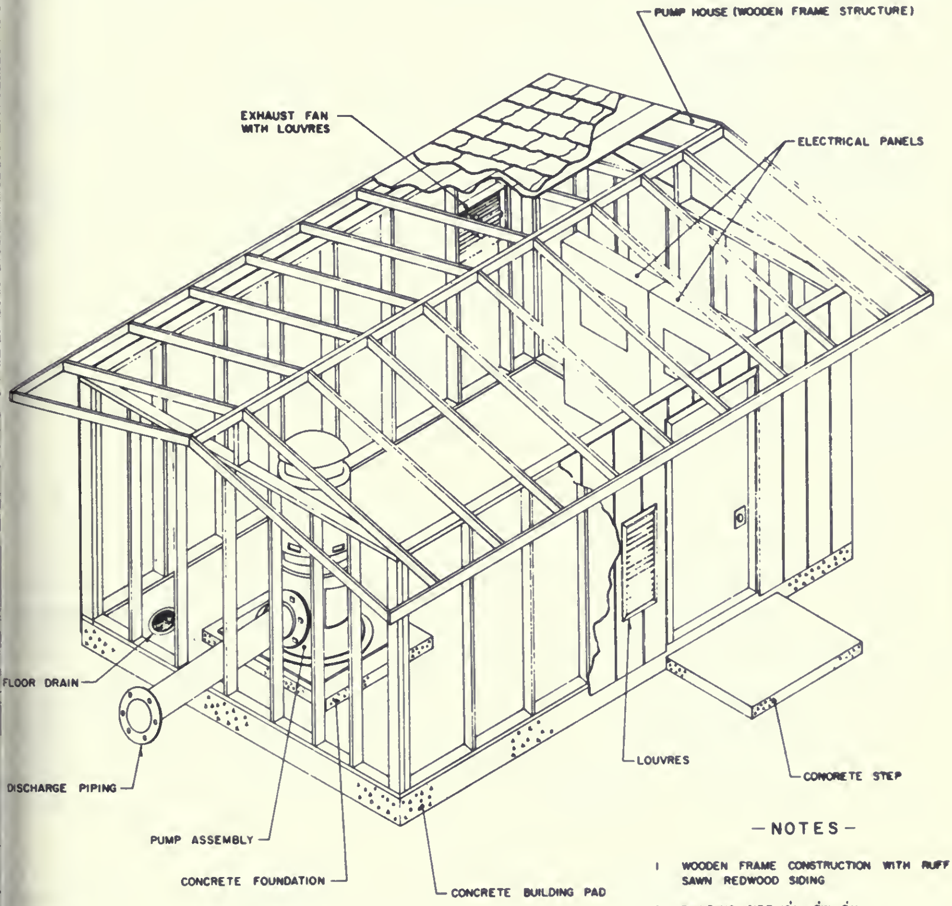
Controls. The pumps would be operated by a remote control system. This system not only will turn the pumps on and off, but will provide flow rate and other information as required. The central control system would be located at the District's Operations Center. Selected piezometers would be monitored continuously by telemetry to the Operations Center.

Cost Estimate. The cost estimate is shown by major facility in Table 3. An excalation factor of 10 percent per year was assumed in determining the final cost of the project. The time to complete Phase II, if it starts immediately after the completion of Phase I, would be approximately three years. This depends, of course, on the availability of materials and equipment and adequate funding.



TYPICAL PARTS LIST	
PART NO.	DESCRIPTION
1	PUMP FOUNDATION
2	GRAVEL REPLENISHMENT PIPE
3	PUMP MOTOR
4	TURBINE HEAD
5	METER ASSEMBLY
6	GROUT SEAL
7	CONTROL CASING
8	GRAVEL PACK
9	PUMP COLUMN
10	WELL CASING
11	PUMP BOWL
12	WELL SCREEN ASSEMBLY
13	WELL CASING PLUG

Figure 10. TYPICAL WELL DESIGN



—NOTES—

1 WOODEN FRAME CONSTRUCTION WITH RUFF SAWN REDWOOD SIDING

2. BUILDING SIZE 12'L x 8'W x 9'H

3 BUILDING DESIGN PERMITS DISASSEMBLY FOR PUMP MAINTENANCE

4 BUILDING DESIGN INCORPORATES ACOUSTIC FACTORS IF REQUIRED

Figure 11. TYPICAL PUMP & HOUSING DESIGN

Table 3

COST ESTIMATE
PHASE II -- DESIGN AND CONSTRUCTION
(Estimate Based on March 1974 Costs)

Item	Activity		Cost
1	Land Acquisition		
	Engineering	$ 84,000	
	Acquisition, Fee Title, and Easements	345,300	$429,300
2	Barrier Well Construction		
	Engineering	$ 23,300	
	Construct 14 Wells @	206,300	229,600
3	Pumps, Motors, and Appurtenances		
	Engineering	$ 11,300	
	8-inch Pumps, 20 HP Elec. Motors and Appurtenances - 14 @ $8,493	118,900	130,200
4	Buildings to House Pumps		
	Engineering	$ 7,500	
	Construction	24,900	32,400
5	Discharge Facilities		
	Engineering	$ 42,400	
	Construction	181,800	224,200
6	Electrical Service		
	Engineering	$ 2,500	
	Construction	49,400	51,900
7	Remote Control Equipment		46,000
8	Construction of 20 Piezometer Wells		
	Engineering	$ 14,500	
	Construction	85,500	100,000
9	Piezometer Telemetry		
	Engineering	$ 5,300	
	Purchase and Installation	92,800	98,100
Total Cost of Phase II (March 1974 estimate)			$1,341,700
Total escalated Phase II cost assuming October 1978 start, 3 years for completion, and 10% per year cost escalation			$2,369,800
Total Phase I and Phase II			$3,110,900

Economic Considerations

The principal economic effects on an area where the ground water basin is subjected to sea water intrusion are the impairment of the ground water basin as an underground storage reservoir, the degradation of the potable water stored in it, and the loss of its value as a fresh water distribution system. Each of these functions, part of which have already been impaired or completely destroyed by salt water intrusion in the Fremont area, has economic value.

The absence of precipitation during the summer months reinforces the seasonal variation in the demand for water. Furthermore, average annual precipitation is not only modest, but also highly variable. Dry years often come in succession for a decade or more. Thus, ground water basins function as natural regulators of runoff and as storage reservoirs for daily and seasonal peaking requirements. These requirements must be met either from surface storage facilities or from ground water basins.

Standby pump and well capacity has been and is much more economical to develop and maintain than surface storage and distribution facilities for the Fremont area. When the additional sizing costs necessary to meet peaking requirements in surface distribution facilities are considered, the critical economic importance of the Fremont ground water basin becomes apparent. If ground water storage is not continuously available for peaking purposes, alternative surface facilities would be required in addition to the District's entitlement in existing reservoirs.

Ten years ago, construction of tank storage cost over $16,000 per acre-foot of capacity. The cost has tripled since then. For large volume surface storage, a more reasonable solution would appear to be the use of earthfill dams and reservoirs. Surface storage facilities to meet the needs of the Alameda County Water District can be conservatively estimated to cost more than $700 per acre-foot. However, there are no economically viable dam and reservoir sites available in the area which could be used to convert the intermittent Alameda Creek flows into a firm water supply. Storage facilities would probably have to be located in the upstream watershed and water transferred by natural streams to the District, a process that would degrade the quality. If the Fremont ground water area were to be further degraded by saline intrusion, the development of additional surface storage would be mandatory, and would involve a large capital investment to provide for the necessary additional capacity.

The Fremont ground water basin also serves as a water filtration and distribution system. That is, water entering the basin through natural and artificial recharge is extracted in a wide area overlying the basin using the aquifers as a natural treatment and distribution system. This has entailed a large capital investment in wells and pumping facilities. The abandonment of the capital investment in wells and pumping facilities would represent a very substantial economic loss. In addition, a very large cost would be incurred to install a treatment plant and comprehensive surface distribution system which would be needed should the basin's capacity to function be destroyed by further saline degradation.

The costs of protecting and operating the ground water reservoir in the Fremont area are compared with the economic benefits in Table 4.

Table 4

SUMMARY OF ECONOMIC CONSIDERATIONS

Economic Benefits	Millions
1. Water Supply Yield	$ 41.7
2. Emergency Storage	18.3
3. Natural Treatment Plant (Net)	26.2
4. Conveyance Capacity	2.5
Subtotal	$ 88.7
Ground Water Basin Costs	
1. Operating Costs (excluding water)	$ 11.7
2. Additional Replenishment and Regulatory Facilities	3.9
3. Aquifer Reclamation (capital & operation)	5.0
4. Salinity Intrusion Barrier (capital & operation)	4.8
5. Miscellaneous	2.0
Subtotal	$ 27.4
Net Benefits	$ 61.3

Benefit Cost Ratio = 88.7/27.4 = 3.2

Optimum Ground Water Use With a Barrier

A significant economic benefit of a salinity barrier comes from protecting the value of the water in storage in the basin and the water supply continually replenishing it. If protected from intrusion, this water supply would continue to be fully available for use in the basin.

To areas such as Fremont, which are becoming increasingly dependent on a large continual supply of imported water, the utility of the ground water basin for regulatory storage represents an important justification for protection. If the Fremont ground water area could be operated with the proposed barrier to saline intrusion -- after reclamation of the intruded aquifers -- then the ground water basin could be used without the threat of further saline intrusion and its inherent costs. However, the cost of installation and operation of the sea water intrusion barrier would be incurred.

With the ground water basin managed under an assumed plan of operation, ground water elevations within the basin could be safely drawn down below sea level within the inland parts of the basin during dry years. In addition, this would provide larger capacity for the storage of inflowing surface water during periods of above-normal precipitation. The benefits of operating the ground water basin with barriers to sea water intrusion along the coastline are that the entire 25,000 acre-foot annual recharge to the ground water basin could thus be operated to provide the required capacity without degradation and without the expense of additional surface storage. In addition, the savings derived from continuing to use the ground water basin as a major distribution facility would further offset the cost of constructing a barrier.

The value of maintaining a ground water basin solely for an emergency water supply constitutes an important justification for protection works. The value of such an emergency supply would be enormous during a period of extended drought, or during times when the surface distribution system was not usable because of any emergency such as earthquake damage, maintenance shutdowns, or enemy action during war. The value would increase with the severity and duration of the emergency.

CHAPTER V. ENVIRONMENTAL CONSIDERATIONS

The proposed project is a dual-purpose, extraction-type sea water intrusion barrier. As shown in Figure 6 (Page 24), it will be an irregular line of wells and piezometers along the landward edge of the saltwater evaporation ponds west of Fremont and extending about 3 miles northward and 6 miles southeastward from the Coyote Hills. The objectives of the project are to (1) effectuate the reclamation of the Newark aquifer through removal of already intruded saline water, and (2) prevent further salt water intrusion.

As indicated in Figure 8 (Page 31), the first phase of the project comprises a series of activities required to complete the exploration for and final design of the project. The activities in Phase I which will have a visible effect on the environment are:

1. Drilling of about 100 exploratory holes by the cable-tool method.

2. Development of about 25 of the exploratory holes at potential barrier well locations after computer analysis of exploratory well log data.

3. Pump testing of the aquifer stringers encountered to both confirm the effectiveness of the proposed well locations and develop data required for design of each barrier well.

Phase II project activities which will have a visible effect on the environment are:

1. Installation of about 14 barrier wells with pumps, housing, discharge facilities and underground utilities.

2. Installation of about 30 piezometers plus remote sensors and telemetry at selected sites.

3. Development of the wells to achieve designed yields without excessive sanding.

4. Operation and maintenance of the installed intrusion barrier/aquifer reclamation project.

The optimum number and exact location of wells and piezometers which may be required to meet project objectives cannot be determined until the locations, depths, and transmissivities of the sand and gravel stringers which comprise the Newark aquifer are determined during Phase I.

Environmental Description

As proposed, the Fremont Salinity Barrier alignment will follow the prominent environmental boundary between the salt water evaporation ponds and the adjacent flats of the bay plain. Much of the alignment had been tidal marsh before levees were constructed to develop salt ponds and grazing land. At the south end of the Coyote Hills, the barrier wells will be near the boundary of the Fremont unit of the South San Francisco Bay National Wildlife Refuge. At the north end of the Coyote Hills, some of the wells and piezometers may be in or near the Coyote Hills Regional Park. Land use near the barrier alignment is primarily agricultural and some industrial. The main habitat types in the area affected by the project are grassland, irrigated and dry farm agriculture, and tidelands including salt marsh, salt ponds, and levees.

Each habitat type provides more or less uniform physical and biological conditions which enable the survival of some highly specialized endemic species and provide food and cover for numerous nondependent and migrant species. In the area that may be affected by the salinity barrier project, the salt marsh habitat is the most critical because of its high biologic productivity and the endangered species whose range is limited to that habitat.

As noted in the "Hayward Shoreline Environmental Analysis", the salt marsh habitat once was one of the dominant elements of the South San Francisco Bay shoreline, in terms of both the area it covered and its ecological significance Today, near the project area, only a few hundred acres remain that still merit this designation. There are two major salt marsh areas, encompassing approximately 250 acres, located north and south of the mouth of the Alameda Creek Flood Control channel. A diked marsh of moderate extent has been mapped northwest of Turk Island; elsewhere, lesser strips and patches can be found along some of the creek channels and sloughs and bordering parts of the bay.

Salt marshes generally occur at levels slightly higher than (and inland from) the tideflats but, like the mudflats, exist in a "not-quite-water, not-quite-land" situation. The environmental rigors of a salt marsh community include, among others, regular fluctuations of temperature and tide. To plants and animals alike, the salt marsh is a "chemical desert" with a scarcity of fresh water, a salty, alkaline soil, and an exposure to the drying effects of wind and evaporation -- conditions which in many ways are as severe to life as those of a climatic desert.

Most types of Bay Area vegetation, whether native or introduced, would find such environmental conditions prohibitively hostile. But in the salt marshes two major plant associations have evolved to flourish under these circumstances; together, they form the basis of a remarkably rich and productive habitat. Near the Project area, each of these associations is dominated by a single plant species. Generally speaking, most salt marsh acreage consists of a solid, dense groundcover of pickleweed (Salicornia sp.), with strips of cordgrass (Spartina foliosa) occupying the shallow sloughs. Cordgrass is tremendously important in the economy of a salt marsh because of its extremely high productivity. Termed the "staff of life" for bay animals, it helps purify the air and produces five to ten times more nutrient material and oxygen per acre than well-known commercial crops such as wheat. Although it provides habitat and foraging niches for certain animals, cordgrass becomes most ecologically valuable when it decomposes, thereby releasing nutrients that are washed into intertidal waters to feed invertebrates and fertilize algae beds.

Unlike cordgrass, which can endure up to 21 hours of continuous submergence, pickleweed -- the most widespread salt marsh plant -- is less water-tolerant and begins its best growth at the average high tide line. Its curious, succulent stems are characteristic of bayshore soils with salt contents as high as 6-1/2 percent, and its root masses give stability to the banks of brackish channelways.

A variety of insects can be found in or around the salt marshlands, including moths, butterflies, beetles, ants, wasps, bumblebees, and the like. As its name implies, the salt marsh fly (Ephydra spp.) lives only around the marshes and salt ponds; likewise, the salt marsh mosquitoes (Aedes squamiger, A. dorsalis) lay their eggs in quiet marshland ponds away from tidal currents.

Some salt marshes around San Francisco Bay play host at high tide to common shallow water fish such as anchovies, smelt, sculpin, and surfperch, with threespine stickleback (Gasterosteus aculeatus) sometimes remaining in nearby sloughs and potholes; however, it is not known if such species inhabit marshlands near the project area.

Near the project area some 27 species of birds have been observed in salt marsh habitat, and at least 8 others -- perhaps more -- may be found there from time to time as well. Over half of these are waterbirds, including a relatively high proportion of "wading" birds, probing shorebirds, and rails, while the rest are species usually associated with adjacent inland areas, such as hawks, insectivorous birds, and others. Two of these birds, the California clapper rail (see Figure 12) and a subspecies of song sparrow are critically dependent upon the salt marsh habitat for their survival. An estimated 30 to 50 California clapper rails -- officially listed by the U. S. Fish and Wildlife Service as an endangered species -- live in the patches of salt marsh at the mouth of the Alameda Creek channel, where they nest in the pickleweed. Some believe that the rare California black rail may also be in the area. The song sparrow subspecies, also a local resident, is restricted in its range to salt marshlands and adjacent dikes about San Francisco Bay from Richmond southward; probably their total population near the project area is at least three to four hundred. It is not on the official lists of rare and endangered species.

The project area is near one of the few known ranges of an endangered species of salt marsh harvest mice (see Figure 12), which is endemic to the salt marshes of South San Francisco Bay, San Pablo Bay, and Suisun Bay. It is a close relative of the western harvest mouse, which is widespread over most of western United States. Interestingly, the salt marsh harvest mouse feeds on pickleweed, drinks salt water, and excretes salt with its urine. By elimination of its habitat, this species is threatened with extinction. Salt marsh harvest mice inhabit the salt marshes near the channel mouth of Alameda Creek. Whether salt marsh harvest mice inhabit the pickleweed stands along the sloughs in the project area is not known.

Despite their spatial limitations, the strips and patches of salt marsh along the shoreline near the proposed barrier project occupy a prominant place in the overall environmental picture. They support a wealth of interrelated -- and sometimes specially adapted -- organisms that range from inconspicuous algae growing on pickleweed stems to graceful marsh hawks soaring overhead. They have served as part of a special "evolutionary laboratory" that today provides sanctuary for several rare and endangered species. Their luxuriant

Figure 12

ENDANGERED SPECIES

California Clapper Rail

(Rallus longirostris obsoletus)

The California Clapper Rail is a hen-sized, long-billed, brown bird with tawny breast, barred flanks, and a short, upturned tail with white beneath. Largest of California's Rails, this secretive bird is seldom seen far from salt marshes. It is highly specialized and apparently incapable of adapting to environmental change. Major populations occur in salt marshes bordering South San Francisco Bay, where they number 2,700 birds. Smaller populations exist in San Pablo Bay and Elkhorn Slough. They are absent from Suisun Bay and many other salt marshes along the north and central coast. Fill and drainage as well as industrial pollution and the introduced old-world rat were threatening their existence. However, with the recent establishment of the South San Francisco Bay National Wildlife Refuge and preservation of key habitat areas, there is opportunity now to develop management plans to remove this Rail from endangerment.

Salt Marsh Harvest Mouse

(Reithrodeotomys raviventris)

This unique mouse inhabits San Francisco Bay brackish and salt marshes. It is recognized by its rich brown back and cinnamon to whitish underparts. It is one of the few mammals able to drink salt water. It was formerly found throughout the extensive marshes once bordering San Francisco Bay, but now is restricted to scattered colonies within its original range. Destruction of salt marsh habitat by Bay fill and diking are major factors contributing to its decline and endangerment.

From *At the Crossroads, 1974, A Report on California's Endangered and Rare Fish and Wildlife.*
California Department of Fish and Game. January 1974

swaths of cordgrass have helped earn the salt marshes their position as the most productive type of natural vegetation in North America.

For the ecological reasons outlined above, salt marshes should be given very high environmental priority in considering the possible effects of the saline waters to be discharged to sloughs and channels from the proposed barrier wells.

A freshwater marsh is located near Coyote Hills; brackish water marshes tending toward fresh water occur in the headwaters of Mowry Slough. Dominant freshwater marsh vegetation types include cattails (Typha spp.) and tules (Scirpus spp.), with bulrushes, spike-rush, and sedges in subdominant roles.

In addition to the salt marsh dependent animals previously discussed, other rare or endangered species may occur in the area. Two migratory birds, the Aleutian Canada goose and tule white-fronted goose, may use this area as stopping grounds during their migrations. Such stopping areas are becoming increasingly scarce due to urban and industrial encroachment.

Project Impacts

During the exploratory and construction stages of the barrier project, the habitat, vegetation, and wildlife would indeed be disturbed near drilling and construction sites. This disturbance would be short term and would consist of increased noise, traffic, and ground vibrations, and decreased visual amenity. These cannot be avoided. However, the impact created by the dumping of mud slurry spoil can be decreased. The dumping area can be minimized, the spoil removed as soon as possible, and the area replanted with plants native to the area.

Any long-term impacts may also be substantially reduced if certain measures are taken. Ambient noise levels will be slightly increased. In any area where this is deemed to be a problem, the well housings could be lined with sound-absorbing materials. Any adverse visual impacts could be decreased by coloring the structures so they blend with the surrounding scenery. A certain amount of land will be removed from biological production due to the construction of well facilities. This is unavoidable, but should be minimal. Any habitat area that is destroyed, for instance by construction of underground utilities, can be restored by replanting with plants native to the area.

This project should have a very minimal effect upon the environment if certain mitigation measures are followed and care is taken to minimize habitat destruction during exploratory and construction operations. Even though ground waters produced by barrier wells and the receiving waters in the sloughs and channels may differ in quality, the effect of the discharged waters on the productivity of the sloughs is expected to be minimal. However, the areas of discharge should be monitored to detect any possible adverse changes.

Several archeological sites have been found near the project area, especially near the Coyote Hills. Such known sites will be avoided. However, if additional sites are discovered as a result of trenching or road grading, work either will be temporarily halted for emergency salvage excavation by an archeologist, or the facility will be relocated, if feasible.

Air quality in the project area, as measured in Fremont, is relatively poor. This area recorded the second highest number of days exceeding the California Ambient Air Quality Standards for oxidant levels in the nine Bay Area counties, Livermore being the highest. Due to the location of the Bay Area and its climate, smog seasons usually occur when it is very warm and cold air from the Pacific forms a temperature inversion layer. This layer is present throughout most of the summer and during a few winter months. Review of the air quality data for Fremont shows that the worst smog season for the project area occurs in September and October.

The effects of this project on the air quality of the area would be short term and probably minimal. The internal combustion engines to be used on the test wells during Phase I would add a very small amount of pollutants to the air. During exploration and construction activities, particulate matter (such as dust and exhaust from machinery) would also be added to the air.

The Fremont area is in a region that has experienced frequent earthquakes, some of which have been strong and destructive. The Hayward fault, which forms a ground water barrier near the apex of the Niles cone, is one of the most active faults in the United States. Estimates of recurrence probability of earthquakes along the Hayward fault indicate that at least two earthquakes of magnitude 5 and one of magnitude 5.5 may be expected each 10 to 20 years. The earthquakes of 1836 and 1868 on the Hayward fault are thought to have had magnitudes greater than 7.

Major earthquakes on the San Andreas and Calaveras faults also could produce destructive shaking in the project area. Shaking damage to barrier wells is not anticipated. On the other hand, lurch cracking could damage discharge pipes and disrupt underground utilities. The most serious earthquake damage which should be anticipated in the project area would be the possible destruction of levee sections and consequent salt water flooding of the barrier well sites and surrounding lowlands.

No inducement of growth in the community will result directly from the project. Indirectly, the construction of the project may contribute in a minor way to sustaining the health of the construction industry -- a growth-oriented industry.

Some people hold that any step taken toward improving the capability of a Water District to provide water to its service area is an inducement to, or operates in support of, growth. To the extent that that belief is correct, the proposed project contributes indirectly to the support of growth in the District's service area.